Discovery of a Binary Quasar

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1. Introduction

The discovery of quasars, about 25 years ago, was one of the most exciting events in the history of recent astronomy. Despite the slow growth in our understanding of their physical nature, these objects, which have the highest known redshifts, still provide the best available probe of the most remote observable regions of the universe. Notwithstanding the numerous observational and theoretical difficulties (few if any of the simplest and most basic questions about quasars can be answered with certainty), the enthusiasm of astronomers for the study of quasars has not declined.

Though long discussed and predicted by Eddington, Einstein, and Zwicky (e.g. see IAU Symposium # 119 and references therein), the still recent discovery of the gravitational lensing phenomenon is one of the most vigorous and growing subjects in modern extragalactic astronomy. A natural expectation, based on the observed degree of galaxy clustering at low redshifts and on reasonable extrapolations to large redshifts, indicates that some of the claimed "gravitational lens" systems are actually physical pairs of quasars with small separations (Bahcall et al. 1986). There are, in fact, several pairs of quasars known, with projected angular and redshift separations indicative of membership in large clusters or superclusters (e.g., 1146+111, 0952+698, and 1037−271). However, there are no *definite* close physical quasar pairs currently known at any redshift. Finding such a QSO pair would be very interesting, as it would provide diagnostics of processes and insight into phenomena which are not probed by the gravitational lensing: e.g. the nature of clustering at large redshifts, the role of gravitational interactions in triggering and fueling of galaxian nuclear activity.

2. The Observations

We report here the discovery of a pair of quasars with a redshift of 1.345, separated by 4.2 arcsec in projection, apparently associated with the radio source PKS 1145-071. It could be the first binary quasar known (Djorgovski et al. 1987).

The radio source OM-076 was first identified with a blue, 17.5^m stellar object on the Palomar Sky Survey by Radivich and Kraus (1971), and then "rediscovered" as PKS 1145-071 by Bolton, Shimmins, and Wall (1975), who confirmed the optical identification. The spectroscopy of the object by Wilkes (1986) identified it as a QSO with z = 1.345. VLBI measurements of the radio source were published by Preston et al. (1985). There was no mention by any author of the source's binary structure.

2a. The Imaging CCD Observations

It is well known that one of the common ways of obtaining the flatfields for an observation night (or even run) consists of taking sky median frames. Then a number of about 5 exposures free of bright and/or very extended objects are obtained during the night. It is of course ideal if the chosen fields have in addition a scientific content!

At La Silla, last December, we took frames for sky median in regions extremely poor in stars but carefully selected for containing quasars which could be possible lens candidates. During the first night, the pair of quasars associated with the radio source PKS 1145-071 was discovered. The QSO was selected on account of a marginal elongation visible on the finding chart!

We obtained initial images of the field on the night of UT 1986 December 29, using the RCA 320 × 512 CCD # 5 mounted at the Cassegrain focus (f/8.01) of the ESO 2.2-m telescope, at La Silla. The effective pixel size was 0.363

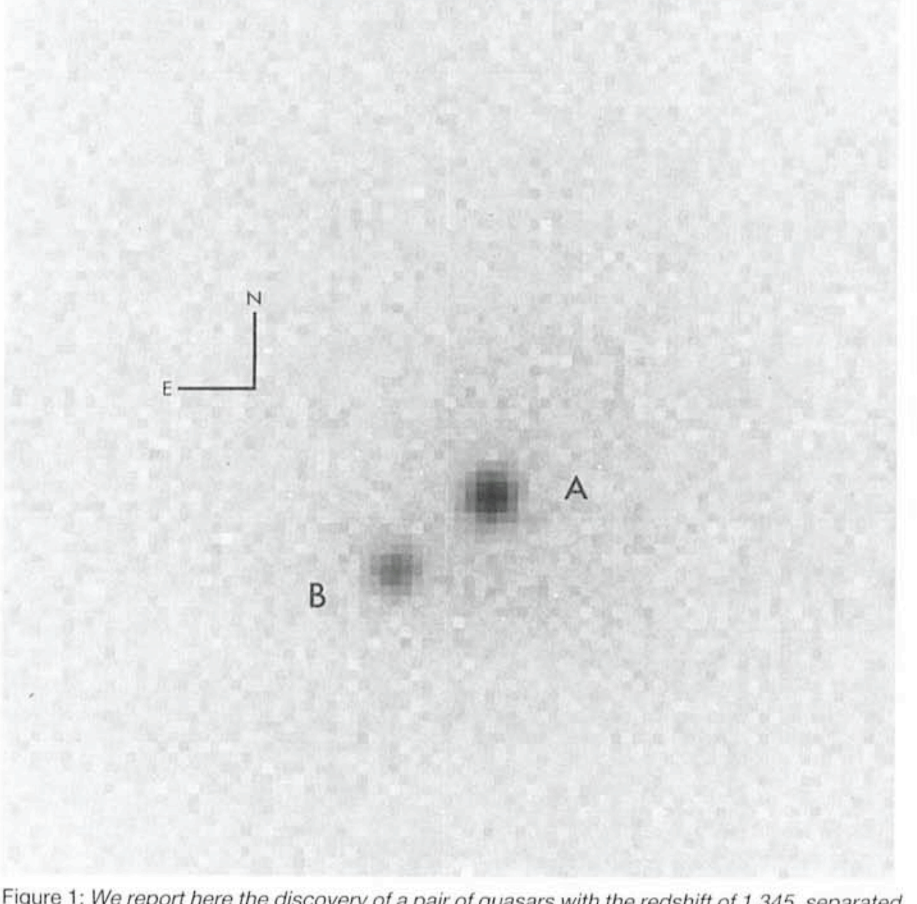

Figure 1: *We report here the discovery of a pair of quasars with the redshift of 1.345, separated by 4.2 arcsec in projection, apparently associated with the radio source PKS 1145-071. Being the first image showing the binary character of this object, this figure displays the B-band CCD frame of the PKS 1145-071 field, obtained at ESO. The two QSO's are labeled as "A" and "B".*

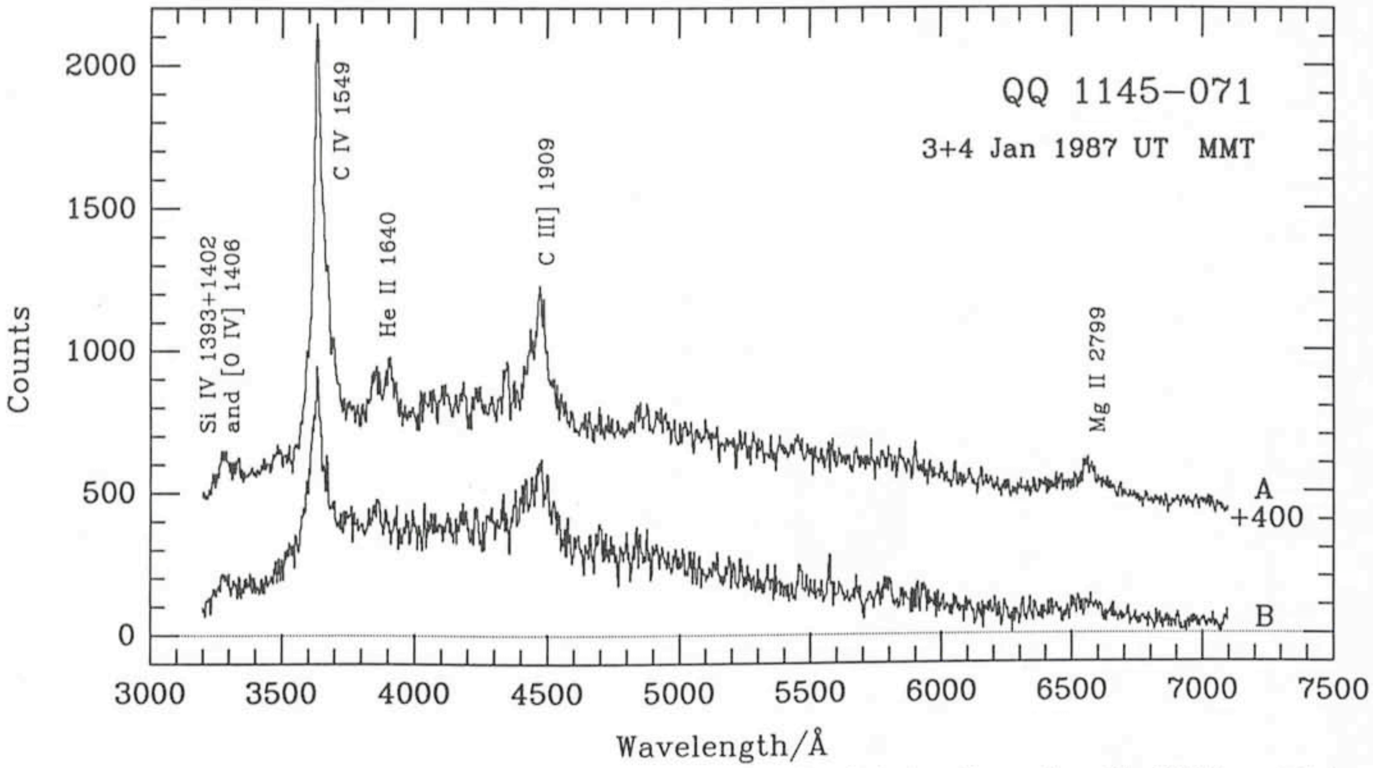

Figure 2: *The spectra of the two quasars, obtained at the MMT: QSO A on the top, B on the bottom. The spectrum of the QSO A was shifted up by 400 units for clarity. Both spectra were rebinned to 3 Å bins (~ the instrumental resolution). The relative flux scale is arbitrary.*

arcsec. The meteorological conditions were not of great quality: marginally non-photometric and with a seeing FWHM $\simeq$ 1.5 arcsec (the next night quite a few frames had FWHM = 0.6 arcsec!). One *B* and one *V* exposure of 300 s each were obtained. The *B* frame is shown in Figure 1.

The separation of the two components is:

$\Delta\alpha_{A-B} = -3.3 \pm 0.1$ arcsec
$\Delta\delta_{A-B} = +2.6 \pm 0.1$ arcsec

which corresponds to a total separation of 4.2 ± 0.1 arcsec in the direction PA = 128°. Our magnitude zero points are uncertain (approximate magnitude of the QSO A is ~ 18), but we can derive accurate intensity ratios for the two images, $I_A/I_B = 2.15 \pm 0.15$ in the *B* band, and 2.7 ± 0.1 in the *V* band.

Because of the equatorial position of this object, it can also be observed from the northern hemisphere: this was the beginning of a cascade of observations!

2b. The Spectroscopic Observations

Spectra of the two components were obtained on the nights of UT 1987 January 3 and 4, by using the Reticon spectrograph on the Multiple Mirror Telescope at Mt. Hopkins. We used the low resolution (300 lines mm^{-1}) grating, and 2 × 3 arcsec entrance apertures. The seeing was fairly good, but transparency variable, which prevented adequate flux calibration of the data. The spectra confirmed immediately that both objects A and B are quasars, at apparently the same redshift. The total integrations for the QSO's A and B were 600 s and 2000 s respectively on 3 January, and 960 s and 2160 s on 4 January.

The total spectra are shown in Figure 2. They appear similar at a first glance. But they exhibit significant differences. The CIV 1549 line clearly has a larger equivalent width in the QSO A. In the A component, the HeII 1640 appears stronger than in B, and with an absorption feature. The MgII 2799 is only marginaly existant in B. The line widths also seem different.

The redshift of this quasar, based on the CIV line alone is $z_A = 1.345 \pm 0.001$. The measurements of the CIV 1549 and HeII 1640 lines for the QSO B are difficult because of blending.

Considerable care was given to the measurement of velocity difference between the two QSO's. We did wavelength calibration in two different ways. We measured redshift difference from the strong CIV line, and from the cross-correlation of spectra, for the two nights separately, using different portions of the spectra, and employed two different centring methods for the emission lines and cross-correlation peaks. Different methods and variation of parameters enabled us to estimate our internal errors.

From the centring of the CIV line only, we obtain $\Delta z_{A-B} = 0.001 \pm 0.003$, independently for both nights, corresponding to the rest-frame velocity difference $\Delta v^{rf}_{A-B} = 300 \pm 800$ km s^{-1}. A more accurate method, cross-correlation using complete spectra in wavelength range 3200–7000 Å, gives $\Delta z_{A-B} = (9.3 \pm 2.7) \times 10^{-4}$, or $\Delta v^{rf}_{A-B} = 280 \pm 80$ km s^{-1} for the 3 January data, and $\Delta z_{A-B} = (6.5 \pm 3.8) \times 10^{-4}$, or $\Delta v^{rf}_{A-B} = 200 \pm 110$ km s^{-1} for the 4 January data, which have somewhat more reliable wavelength calibration and a better signal-to-noise ratio. Similar numbers are obtained if one uses the wavelength range 3200–4800 Å. However, if we exclude the portion dominated by the CIV line, and use the data in the range 3800–7000 Å, the difference drops to $\Delta z_{A-B} = (4.1 \pm 3.1) \times 10^{-4}$, or $\Delta v^{rf}_{A-B} = 120 \pm 90$ km s^{-1} for the 4 January data (the 3 January data do not have enough signal to do this test).

2c. Radio Observations

Short observations of PKS 1145-071 were obtained with the Very Large Array (VLA) on the night of UT 1987 January 9. In view of the configuration available ("C"), only the data taken at 2 and 1.3 cm had sufficient resolution to clearly determine whether the object contained two points of emission, or one. All the data were calibrated by short observations of nearby point sources. Subsequently, the standard self-calibration

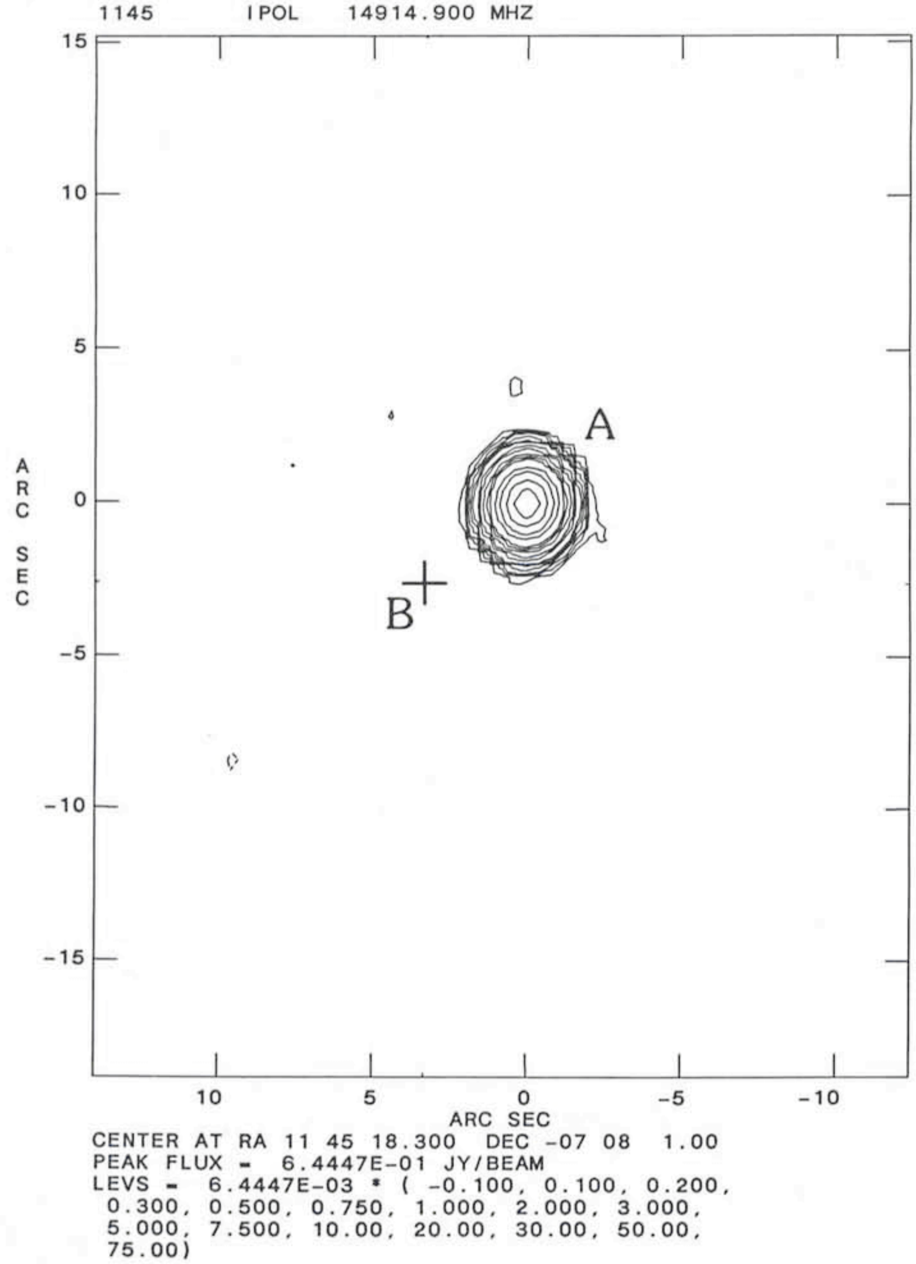

Figure 3: *Radio map of PKS 1145-071, obtained at VLA at 2 cm, in the C configuration. The position of the QSO B is marked with the cross. The residual noise in this map is 0.23 mJy.*

routines were applied, and the resulting maps have excellent dynamic range, ~ 2700 : 1 at 2 cm and 6 cm, and ~ 200 : 1 at 1.3 cm. The 2 cm map is shown in Figure 3. The source is unresolved at all frequencies, and there is no trace of a secondary image.

The best-fit radio position of the source (epoch 1950.0) is:

$$\alpha = 11^h\,45^m\,18.29^s$$
$$\delta = -07^\circ\,08'\,00.56''$$

with errors of 0.05 arcsec in each coordinate. We obtained the optical position of the brighter of the two QSO's from the independent measurements of both red (E) and blue (O) prints of the Palomar Sky Survey, by using the Center for Astrophysics dual axis measuring machine. Some 20 SAO stars were used to establish the coordinate system. The final mean position (epoch 1950.0) is:

$$\alpha = 11^h\,45^m\,18.30^s$$
$$\delta = -07^\circ\,08'\,01.05''$$

with errors of 0.6 arcsec in each coordinate. There is thus no doubt that the radio source is associated with the QSO A.

3. Discussion and Conclusions

There are only a few systems for which the gravitational lensing interpretation is now reasonably well established, viz., 0957+561, 1115+080, 2016+112, and probably 2237+030. To this date there is no detection of lens objects in two other possible cases, 1635+267, and 2345+007. The non detection of any lens object is of course not equivalent to the non existence of such object! Nevertheless these two last cases could be regarded also as tentative true pairs of physically distinct quasars.

In the case of PKS 1145-071, the imaging and spectroscopic data are marginally consistent with the interpretation of the pair as a gravitational lens. The crucial evidence comes from our radio maps: the intensity ratio on cm wavelengths is *at least several hundred,* which should be compared to the optical intensity ratio of ~2.5. In order to salvage the gravitational lens hypothesis, we would require dramatic L_{Opt}/L_{Radio} variability on the time scales corresponding to the path delay (~1 year), a variability never before observed for an extragalactic source. We thus conclude that the QSO pair 1145-071 is most likely a genuine binary quasar. The above pair has the smallest angular separation known for this kind of objects.

It is tempting to compare this system with the two other QSO pairs, 1635+267 and 2345+007, both of which are radio-quiet, and for both of which the spectroscopic and imaging evidence for gravitational lensing are about equally good as in the case of 1145-071 here. For these two systems there is no obvious lensing cluster and/or galaxy to very faint magnitude levels. Pending further studies, we should leave these two cases open, as they may be interpreted either way.

A physical binary quasar should be an interesting object to study, as it may provide us with some clues about the origin and the fuel of QSO activity. Evidence for tidal interactions is often indicated in the low-redshift QSO-galaxy associations, and even proposed as a possible trigger of the QSO activity (cf. Stockton 1986, and references therein). Tidal shocks may facilitate a runaway gravitational collapse of the central cluster in participating galaxies, and thus actually form the central "engine", or feed more stars and gas into it if it already exists. Galaxy collisions also provide plausible means of transporting the ISM fuel to the central engines. In the 1145-071 A+B system we may be seeing such fateful interaction occurring at an early epoch when the comoving density of quasars was considerablay larger than it is today. In any case, the projected separation and the velocity difference between the two QSO's are consistent with a tidal encounter.

To interpret our data in terms of physical scales, we note that in a Friedman cosmology (with $H_o = 100$ km s^{-1} Mpc^{-1}, $\Lambda_o = 0$, and $q_o = 0$), the distance modulus to the system is $(m-M) = 44.1$, and the projected separation of 4.2 arcsec corresponds to 25.0 kpc. If we substitute $q_0 = 1/2$, these numbers become 43.44, and 18.1 kpc respectively.

From the knowledge of the projected separation a of the two components and from the (significant) difference in velocity between A and B, it is possible to determine a direct estimation of the total mass of the system, under the hypothesis of orbital motions of the two components around their centre of gravity of the system. Using Kepler's third law, we have:

$$(M_A + M_B) \sin^3 i = 2.89\ 10^5 \ \frac{a}{kpc} \ \frac{V^2}{km^2 s^{-2}} \ M_\odot \qquad (1)$$

If we take a = 25.0 kpc and V = 250 km/s (mean of the determinations using the complete spectra, i.e. 3200–7000 Å), for $\sin i = 1$, the total mass of the system equals $M_A + M_B = 4.5\ 10^{11}\ M_\odot$ (lower bound).

Concerning absorption lines, it is worth mentioning that, with an angular separation of 17.9 arcmin, the projected distance between the lines of sight to the two quasars Tololo 1037-27 and Tololo 1038-27 is of the order of 4 Mpc. Thus the absorption line systems in these two quasars could give the largest distance over which correlated absorption quasar spectra has been reported to date (Ulrich 1986). In the case of PKS 1145-071 A+B, the absorption feature in the HeII 1640 of the A component only could give the smallest distance (less than 25 kpc) known so far over which differential absorption is observed, the intervening material being only at a very small distance from the concerned object.

Another exciting possibility is that this pair is situated towards a high-redshift galaxy cluster: if quasars are rare events, then two quasars could be suggestive of a high galaxy density. Mere existence of rich clusters at such large redshifts provides an interesting timing constraint for the theories of large-scale structure formation. No such rich environment is visible on our short exposure frames. Studies of "normal" galaxies in this hypothetical cluster (i.e., those *not* selected by their large radio power, or strong line emission) should be extremely valuable for the investigations of galaxy evolution at large look-back times. Deep imaging and spectroscopy are needed to pursue this potentially highly rewarding possibility, an ideal proposal for the VLT!

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References

Bahcall, J., Bahcall, N., and Schneider, D. 1986, *Nature* **323,** 515.
Bolton, J., Shimmins, A., and Wall, J. 1975, *Austr. J. Phys. Suppl.* **34,** 1.
Djorgovski, S., Perley, R., Meylan, G., and McCarthy, P. 1987, *Astrophys. J. Lett.* submitted.
Preston, R., Morabito, D., Williams, J., Faulkner, J., Jauncey, D., and Nicolson, G. 1985, *Astron. J.* **90,** 1599.
Radivich, M., and Kraus, J. 1972, *Astron. J.* **76,** 683.
Stockton, A. 1986, *Astrophys. Space Sci.* **118,** 487.
Ulrich, M.-H. 1986, in proc. of *Second ESO/CERN Symposium*, G. Setti and L. van Hove, eds., p. 87.
Wilkes, B. 1986, *Monthly Notices Royal Astron. Soc.* **218,** 331.

Preliminary Abundances in Three Cool Supergiants of the SMC

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Introduction

It is quite well known that the objects of the Magellanic Clouds (even the younger objects) have lower abundances of heavy elements than similar objects of our Galaxy (see for example Lequeux, 1983). The whole history of the chemical evolution of the Magellanic Clouds is not yet fully understood. Stellar spectroscopy can contribute to a better knowledge of the abundances in the MC. The pioneering work of Przybylski was begun a long time ago (LMC, 1968, SMC, 1972) using photographic plates at the coudé spectrograph of the 1.88-m (74-inch) telescope at Mount Stromlo. Subsequent work was made by other astronomers, especially by B. Wolf (1972, 1973) using similar techniques at the ESO 1.5-m spectrographic telescope. The use of photographic plates (the only detector available for such a problem at that time) pushed the astronomers towards the observation of blue (hot) stars, since the sensitivity of photographic emulsions is at maximum in the blue part of the spectrum. Foy (1981) and Thevenin and Foy (1986) used the ESO ECHELEC spectrograph and the electronic camera (Baranne, 1976) for the analysis of cooler supergiants.

New Observations and Analysis

As soon as the CASPEC spectrograph with its CCD detector became available (D'Odorico et al., 1983) it appeared that it was perfectly suited for the determination of stellar abundances (D'Odorico et al., 1985; Spite et al., 1985; Spite, 1986). M. Dennefeld called our attention to the subject of the abundances in the Magellanic Clouds, and we decided to try to improve the previous knowledge about the abundances in the Clouds by careful observations and analysis of a few supergiants. Some difficulties in this task are obvious. The determination of the temperature of such stars is affected by uncertainties (the calibration of the colours of the supergiants is not completely reliable, the reddening of the stars is not accurately known and the profiles of the hydrogen lines are not always reliable). Moreover, these stars, even when not known as variable, may still be slightly variable. Finally, the spectral lines could be affected by non-LTE effects.

The best way to tackle this problem was to select rather cool supergiants for observation. The spectra of cool stars display numerous absorption lines: faint and strong lines, lines originating from low and high excitation levels, lines of various elements. From the accurate measurements of these lines, a number of constraints are found for the model atmosphere, so that, by iteration, a model can be adjusted, from which reliable abundances can be derived. The best accuracy of the measurements of the equivalent widths of lines is achieved when using the red part of the spectrum, where the continuum is more easily determined, and this is made possible by the good sensitivity of the CCD detector in the red.

Observations of supergiants were begun at the ESO 3.6-m telescope with the CASPEC spectrograph, but the programme was severely disturbed by